University of Colorado at Boulder

## AEROSPACE ENGINEERING SCIENCES SEMINAR

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# Extreme Event Simulation of Coupled Problems: The Particle Finite Element Method (PFEM)

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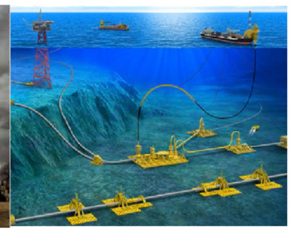

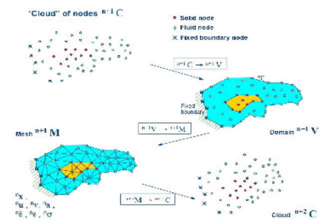


In the computer simulation of mechanical systems, a **coupled problem (CP)** is characterized by the **dynamic interaction** of **heterogeneous subsystems** that are better understood when treated as individual entities. Subsystems may be physical components modeled as fluids, structures, soil, thermal, acoustic or electromagnetic fields; discrete physical components such as a control device, or artificial contraptions such as a moving mesh. The oldest **CP** is fluid-structure interaction (FSI), studied since the late 1920s, and which evolved since into a well studied area: **aeroelasticity**. After digital computers appeared, CPs expanded in scope and prompted the appearance of **multiphysics.**

**CP**s may be divided into "**nice**" and "**rough**". The former are benign in that they can be treated by linking software developed for each of the subsystems, whence programs (or modules) advance in time while exchanging information at each step. This approach, called **partitioned solution**, was created in the mid 1970 by Park, Felippa and DeRuntz at Lockheed Palo Alto Research Labs responding to a specific concern: assessing the vulnerability of the US strategic submarine fleet to nuclear tipped torpedoes. It has the advantage of allowing custom treatment of components; for example in FSI the structure might be modeled by FEM while the fluid is treated by FVM, FDM or BEM as appropriate. This facilitates reuse of existing software (public or commercial) as well as selective upgrading.

**Rough CP**s require a more integrated and specialized treatment. Examples: dam collapse, tsunami engulfing a nuclear plant, ice melting, tunnel excavation, injection mining, combustion, asteroid impact. These include so-called **extreme events**. Common features: fragmentation and recombination, boundaries change each time step. The particle finite element method (PFEM) is intended for such problems. The continuum is "lumped" into **particles**, which are ordinary finite elements that move in space and time in a pure Lagrangian framework. Originally invented for multiphase fluids in Argentina in a thesis under Sergio Idelsohn, it has been extensively developed since 2003 at the Centro Internacional de Metodos Numericos en Ingenieria (CIMNE) in Barcelona, Spain, under the direction of Eugenio Onate. The method is making inroads in the EU but remains largely unknown in the US. Since 2008 I have worked in cooperation with CIMNE re the mathematical foundations of PFEM, with special focus in the difficult areas of numerical stabilization and achieving observer invariance. My approach relies on creating advanced variational methods that incorporate high order field derivatives. This talk will give a summary of PFEM, its current applications, and progress in the stated objectives. Lots of pictures and movies; equations will be avoided.